Joining Composite Parts with Off-Stoichiometric Matrix Reflow

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Poster ID #: PS23-0000000028

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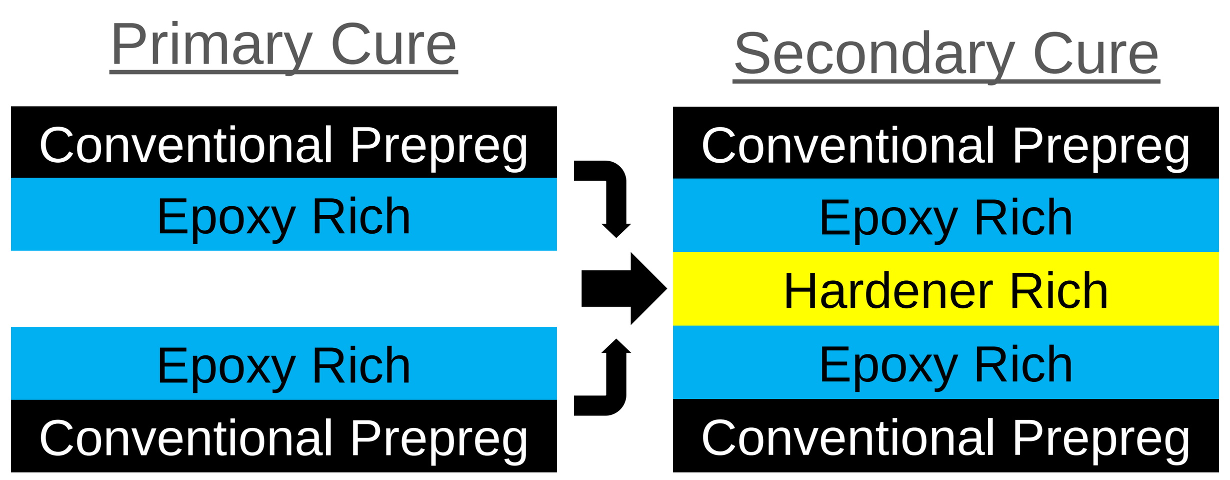
Introduction

Adhesive bonding is an attractive alternative to fasteners for composite part assembly. In addition to superior performance, it reduces weight and eliminates costly manufacturing processes. However, current adhesive bonding methods are highly susceptible to contamination flaws, and it is difficult to verify bonds because nondestructive testing to quantify bond strength is still under development. In aerospace applications, this often results in fasteners being added to provide redundant load paths. Co-cured parts can provide an alternative because they can be inspected using traditional non-destructive evaluation techniques such as ultrasound. However, co-curing can only be accomplished for a limited range of geometries. NASA's Adhesive Free Bonding of Composites (AERoBOND) is an alternative method for bonding composite parts. The goal of this study was to further develop and understand the capabilities of this novel bonding technique.

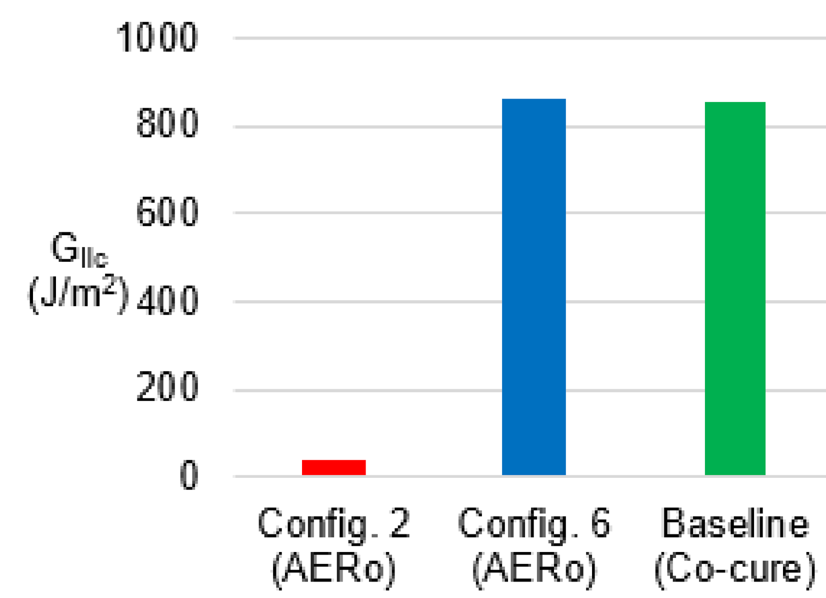
AERoBOND Fabrication Method



The AERoBOND method utilizes a secondary curing phenomenon known as matrix reflow. Parts were fabricated with an epoxy rich (ER) matrix at the faying surfaces for the primary curing cycle. This stoichiometric offset prevented the curing reaction from completing. Bonding was achieved when a ply of complementary, hardener rich (HR), material was introduced between the parts during a secondary curing cycle.

Selected Experimental Configurations

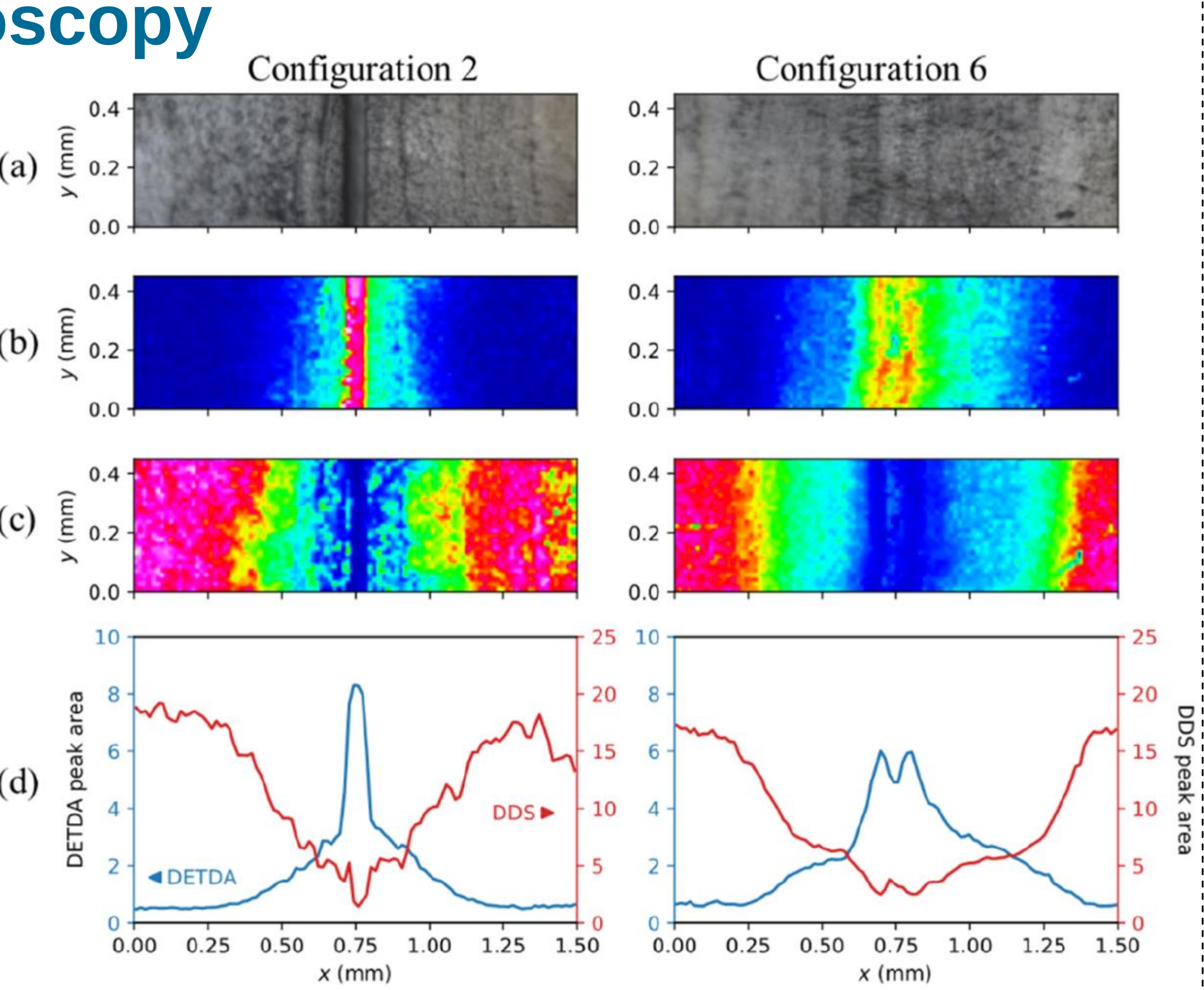
	Configuration 2	Configuration 6
G_{IIc} (% baseline)	5	101
G_{IIc} (J/m²)	43	862
ER *r*-value	0.15	0.1
ER Resin Content	63%	63%
ER # of plies	2	2
HR *r*-value	2.5	2.5
HR Resin Content	77%	49%
HR # of plies	1	1
HR Fiber	Glass Scrim	Unidirectional Carbon
Prim. Hold 1 (min)	N/A	150
Prim. Hold 1 (°C)	N/A	121
Prim. Hold 2 (min)	120	180
Prim. Hold 2 (°C)	178	135



Two configurations of AERoBOND are presented above [1]. Mode-II fracture toughness (G_{IIc}) was used as an indicator of bond quality. Baseline fracture toughness was 855 J/m² for a co-cured part. Poor performance was associated with initial AERoBOND configurations that had longer primary cures and utilized glass scrim in the HR ply. Performance was improved when thermal budget during primary cure was reduced, as in Configuration 6. This reduced degree of cure at the surface, thereby increasing matrix reflow during secondary curing.

Infrared Spectroscopy

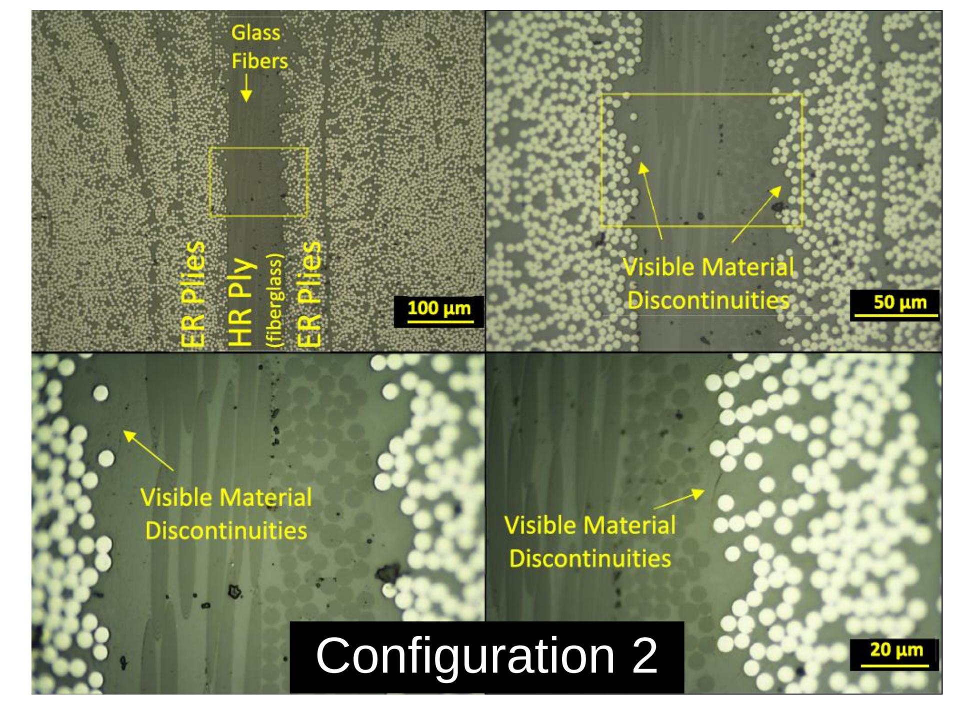
Spatially resolved Infrared spectroscopy using an Infrared microscope was performed on bondline cross sections to identify relative concentrations of diethyl toluene diamine (DETDA) hardener (from the ER and HR material) and 4,4′-diaminodiphenyl sulfone (DDS) hardener (from conventional material). The average signal intensity plots [1] show a more gradual transition between the two hardeners for configuration 6, indicating a higher degree of matrix reflow.

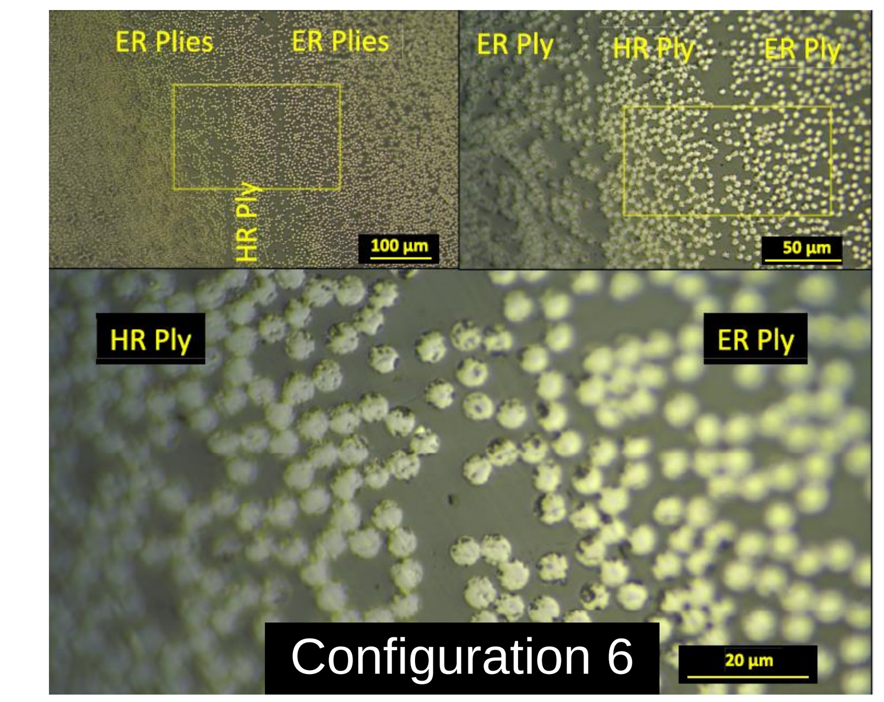


(a) Optical micrographs of the joint. (b) Signal intensity map for the 1614 cm^{-1} peak (DETDA hardener). (c) Signal intensity map for the peak at 1293 cm^{-1} (DDS hardener). (d) Average signal intensity plot.

Microscopy

Panels were examined at the bondline using optical microscopy [1]. Configuration 2 showed a large gap between fiber regions indicating low matrix reflow during secondary cure. This was attributed to the relatively high degree of cure during primary curing, which limited matrix reflow. Increased matrix reflow in configuration 6 led to nesting of fibers across the bondline. The AERoBOND process effectively eliminated the bondline, creating a final product that appears more like a co-cured part than two bonded pieces.





Conclusions

The primary factor for making the AERoBOND process effective is believed to be maintaining a reflowable interface after primary cure followed by a high degree of diffusion across the interface during secondary cure. Thicker ER layers with higher resin content, lower initial ER *r*-value, and lower primary cure temperatures all contribute to preventing gelation during primary cure, ensuring that reactive groups remain intact for secondary curing. AERoBOND shows strong potential, with some configurations exceeding the performance of the baseline process. Investigation to further develop and understand the capabilities of this novel bonding technique are ongoing.

References and Acknowledgements

1. Palmieri, Frank L., Tyler B. Hudson, Austin J. Smith, Roberto J. Cano, Jin Ho Kang, Yi Lin, Lauren J. Abbott, Bryson Clifford, Isaac J. Barnett, and John W. Connell. "Latent cure epoxy resins for reliable joints in secondary-bonded composite structures." Composites Part B: Engineering 231 (2022): 109603. https://doi.org/10.1016/j.compositesb.2021.109603
2. Smith, Austin J., Jonathan A. Salem, Tyler B. Hudson, and Frank L. Palmieri. "Interlaminar mechanical performance of latent-cure epoxy joints." Composites Part B: Engineering (2023): 110567. https://doi.org/10.1016/j.compositesb.2023.110567

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